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Utilization of Biomass Based Fuel in a Naturally Aspirated Diesel Engine

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Abstract

Depletion of petroleum reserves as well as concern over emission problems has now compelled us to widen our search for alternative fuels for heat and power applications. Solid fuels such as wood, charcoal, palm shell and coal are being tested extensively. In liquid fuels, methanol, ethanol and even vegetable oils have been successfully used after alcoholysis. There has been renewed interest in the use of vegetable oils for making biodiesel due to its less polluting and renewable nature as against the conventional petroleum diesel fuel. Various researches are being made to make emulsions with wood pyrolysis oil (WPO) with diesel to overcome the miscibility problem. However, in this issue, an attempt has been made to replace a certain percentage of Jatropha methyl ester (JME) with WPO, it can improve the economic prospects of biodiesel. In this investigation, performance and emission characteristics of a diesel engine fueled with JME-WPO emulsions were studied and those results were compared with baseline diesel and presented in this paper.

Keywords: Biofuel; Bio-oil; Biodiesel; Diesel engine; Performance; Emission

Nomenclature

WPO	Wood pyrolysis oil
JME	Jatropha methyl ester
CO_2	Carbon-di-oxide
HC	Hydrocarbon
CO	Carbon monoxide
NO	Nitric oxide
JOE	Jatropha oil emulsion
BSFC	Brake specific fuel consumption

1. Introduction

In recent years, there has been a steadily increasing in the amount of solid wastes because of the increasing human population and urbanization. Solid waste includes waste matter, including municipality solid waste (MSW), industrial waste, agricultural waste, forest waste and waste bi- products. Biomass can be considered as the best option and has the largest potential which could insure fuel supply in the future. Beside, biomass helps the atmospheric CO_2 recycling and does not contribute to the greenhouse effect. Biofuel from biomass consumes the same amount of CO_2 from the atmosphere during growth as is released during combustion. Also, overall CO_2 emissions can be reduced because biofuels are CO_2

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neutral fuels. The bio mass can be converted into useful energy by adopting different techniques such as dry combustion, anaerobic digestion, bio photolysis, pyrolysis, liquefaction, gasification, hydrolysis and solvent extraction [1]. Out of these techniques, pyrolysis has advantages like simple method, low pressure operation, negligible waste product and high conversion efficiency in the order of 83%. It is the thermal decomposition process of waste substances in the absence of oxygen or little presence of oxygen. Pyrolysis of biomass yields solid, liquid and gaseous products like char, pyrolytic oil and pyrogas [2].

Bio fuels produced from lignocellulosic materials and vegetable oils provide a feasible solution to the twin crises of fossil fuel depletion and environmental degradation. Biodiesel is considered as a promising alternative fuel for diesel engines. It is an oxygenated fuel made from vegetable oils and animal fats by the conversion of the triglycerides to esters (primarily methyl esters) via various esterification processes [3]. The fuel characteristics of biodiesel are similar to that of fossil diesel fuel and it permits the biodiesel to use as a direct fuel for diesel engines without any major modification. Its additional advantages include outstanding lubricity, excellent biodegradability, superior combustion efficiency and low toxicity, among other fuels [4]. Many studies show that unburned hydrocarbons (HC), carbon monoxide (CO) and sulfur levels are significantly less in the exhaust gas, while using biodiesel as fuel. However, a noticeable increase in the oxides of the nitrogen (NO_x) levels is reported with biodiesel [5].

Although biodiesel is considered as a potential alternative fuel, it has some demerits like poor cold flow properties and lower oxidation stability than petroleum fuels [6]. Saturated compounds are responsible for the unfavorable cold flow properties observed in bio-diesel, and the unsaturated esters are mainly responsible for the reduced oxidation stability [6]. Treatment with oxidation inhibitors containing hindered phenols is the most common approach to increase the oxidative stability of bio-diesel.

Wood pyrolysis oil (WPO) is a free flowing dark –brown organic liquid accompanied by a strong acid smell. The oil comprises of different size molecules which are derived from depolymerization and fragmentation reaction of three biomass building blocks: cellulose, hemicellulose and lignin [7]. It has high oxygen content and moisture content but a poor volatility, high viscosity, corrosiveness and cold flow properties which limit their uses as just additives in transportation fuel rather than being used as transportation fuels themselves. WPO cannot be made to mix directly with diesel due to poor miscibility, different surface tension and hydroscopic characteristics [8].

The application of an emulsification technique has been considered to be one of the possible approaches to reduce the production of diesel engine pollutants, as well as the rate of fuel consumption [9]. In this issue, the authors have tried to replace a certain percentage of biodiesel (Jatropha methyl ester indicated as JME) with WPO, it can improve the economic prospects of biodiesel. For this purpose a mixed surfactant prepared by mixing Span-80 and Tween-80 equally by volume was used, which will reduces the difference in surface tension between JME and WPO. In this investigation performance and emission characteristics of a single cylinder, four stroke, air-cooled, direct injection diesel engine was studied with the emulsions made with WPO and JME and the results were compared with diesel and presented in this paper.

2. Materials and Methods

2.1 Production and fuel properties of WPO

The WPO used in this investigation was produced from the pine wood feed stock by pyrolysis process. The experimental setup and the steps involved in the production of WPO were described by the authors in their earlier work [10].The properties of WPO is compared with diesel fuel and given in Table 1.

2.2 Emulsification of WPO and JME

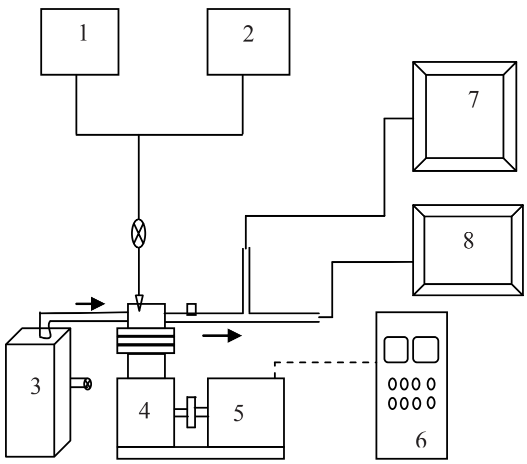
In this investigation, the water in oil emulsion was prepared by adding the mixed surfactant (Span-80 and Tween-80) 2% by volume to emulsify the WPO with JME. Jatropha oil emulsions (Y2JOE5, Y2JOE10 and Y2JOE15) were prepared by taking 5, 10 and 15 percentages by volume of WPO with 95, 90 and 85 percentages by volume of JME. The resultant mixture was stirred with the help of a mechanical stirrer for about 30 minutes. The emulsion produced was observed visually by about eight hours and found that the emulsions made were stable.

Table 1. Comparison of WPO with diesel and JME

Properties	Diesel	WPO	JME
Specific gravity at 15 °C	0.83	1.15	0.88
Net calorific value (MJ/kg)	43.8	20.58	39.1
Flash point (°C)	50	98	118
Fire point (°C)	56	108	126
Pour point (°C)	-6	2	-1
Carbon residue (%)	0.1	12.85	-
Kinematic viscosity at 40 °C (cSt)	2.58	25.3	4.6
Cetane number	50	27	55
Moisture content (wt %)	0.025	15-30	-
Carbon (%)	86.5	49.1	77.1
Hydrogen (%)	13.2	6.2	11.81
Nitrogen (%)	Nil	3.0	0.119
Sulphur (%)	0.3	0.05	0.001
Oxygen (%)	Nil	41.65	10.97

2.3 Experimental Setup

Fig.1 shows the schematic diagram of the experimental setup. Technical specifications of the engine were given in Table 2.



1. Diesel Tank 2. Emulsion tank 3.Air box
4. Engine 5. Alternator 6. Resistive load
7. Gas Analyzer 8. Smoke meter

Fig. 1. Schematic diagram of the experimental setup

The engine was coupled to an alternator to provide the loading. A control panel located near the engine helps to operate the alternator to provide the load to the engine by a load switch. The exhaust gas temperature was measured with the help of a temperature thermocouple fitted on the exhaust pipe. Fuel was admitted from fuel tank to the engine through a fuel filter and fuel pump. The fuel consumption was measured with the help of a burette and a fuel sensor. Air enters to an air filter and then to air box. Air intake was measured by air flow sensor that was fitted in the air box. A speed sensor was connected near the flywheel of engine to measure the speed. The exhaust pipe had a provision to access the probes of an AVL444 exhaust gas analyser that measures unburnt hydrocarbon (HC), carbon monoxide (CO) and nitric oxide (NO) emissions. HC and NO emissions were measured in ppm and CO is measured in percentage. An AVL437C diesel smoke meter was used to measure the smoke density of the engine exhaust. Initially the engine was operated with neat JME for obtaining reference data. The performance and emission parameters were evaluated. Then, the engine was allowed to run with the three emulsions made with Y2JOE5, Y2JOE10, Y2JOE15 (5, 10 and 15 were percentages by volume of WPO and remaining percentages of JME). The test was conducted three times consecutively and the repeatability of the results was coincided more than 97%. The results were compared with diesel fueled and jatropha fueled operations.

Table 2. Specifications of the test engine

Make/Model	Kirloskar TAF 1
Brake power [kW]	4.4
Rated speed [rpm]	1500
Bore [mm]	87.5
Stroke [mm]	110
Compression Ratio	17.5:1
Nozzle Opening Pressure [bar]	200
Injection Timing [ºCA]	23

3. Results and discussion

3.1 Performance parameters

3.1.1 Brake Thermal Efficiency

The variation of brake thermal efficiency with brake power is given in Fig.2. Thermal efficiency is the ratio between the power output and the energy introduced through fuel injection, the latter being the product of the injected fuel mass flow rate and the lower heating value.

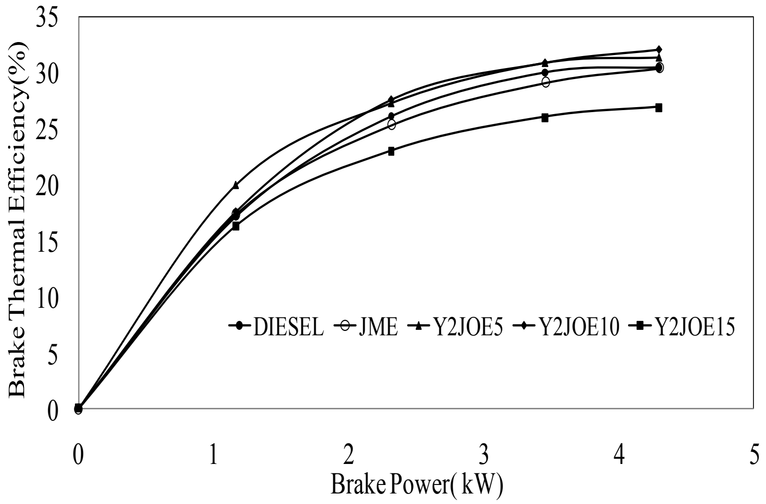


Fig. 2. Variation brake thermal efficiency with brake power

It is observed from the figure that the brake thermal efficiency of the Y2JOE5 and Y2JOE10 emulsions are 2.8% and 5.3% higher than that of diesel fuel. For Y2JOE15 emulsions the thermal efficiency drops by 11.6%. The increase in brake thermal efficiency of Y2JOE5 and Y2JOE10 are due to the improvement of the combustion process on account of increased oxygen content in the fuels [11]. In the case of Y2JOE15 emulsions, the drop in the thermal efficiency may be due to lower calorific values of the emulsions.

3.1.2 Brake Specific Fuel Consumption (BSFC)

The variation of specific fuel consumption with brake power is shown in Fig.3. Brake specific fuel consumption is the ratio between mass of fuel consumption and brake power.

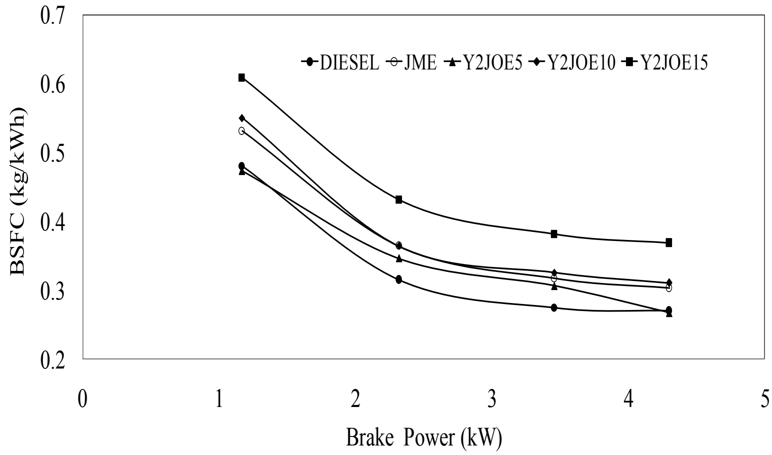


Fig. 3. Variation of brake specific fuel consumption with brake power

The BSFC of diesel, JME, Y2JOE5, Y2JOE10 and Y2JOE15 at full load are 0.269, 0.302, 0.266, 0.31 and 0.368 kg/kWh respectively. Also it can be observed that the BSFC values of JME, Y2JOE10 and Y2JOE15 are higher than diesel fuel operation. This is because of the combined effects of lower heating value and the higher fuel flow rate due to high density of the JME and its emulsions with WPO [12]. In case of Y2JOE5, the BSFC value is slightly lower which may be attributed to better air fuel mixing which leads to better combustion.

3.2 Emission parameters

3.2.1 CO_2 emissions

Fig.4 depicts the variation of CO_2 emissions with brake power.

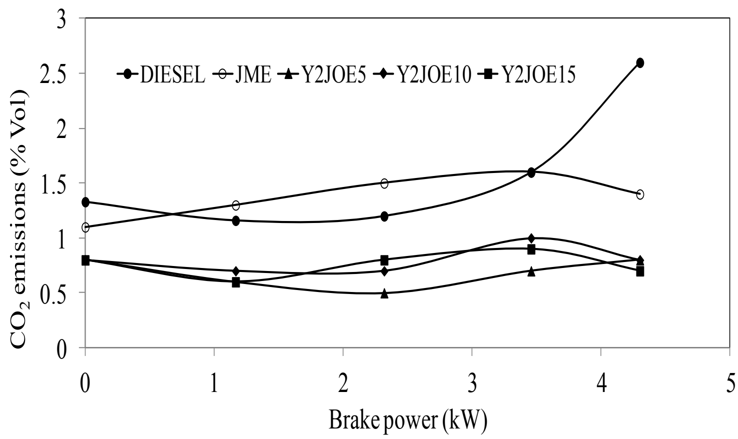


Fig. 4. Variation of CO_2 emissions with brake power

It is observed from the figure that the CO2 emissions of JME and JME-WPO emulsions are lower than that of diesel fuel at full load. This is attributed to the fact that biodiesel is a low carbon fuel and has a lower elemental carbon to hydrogen ratio than diesel fuel [13].

3.2.2 NO emissions

The variation of nitric oxide (NO) emissions with brake power is presented in Fig.5. NO is formed by chain reactions involving nitrogen and oxygen in the air. These reactions are highly temperature dependent. Since diesel engines always operate with excess air, NO emissions are found to be more. Also NO emissions are mainly a function of gas temperature and residence time.

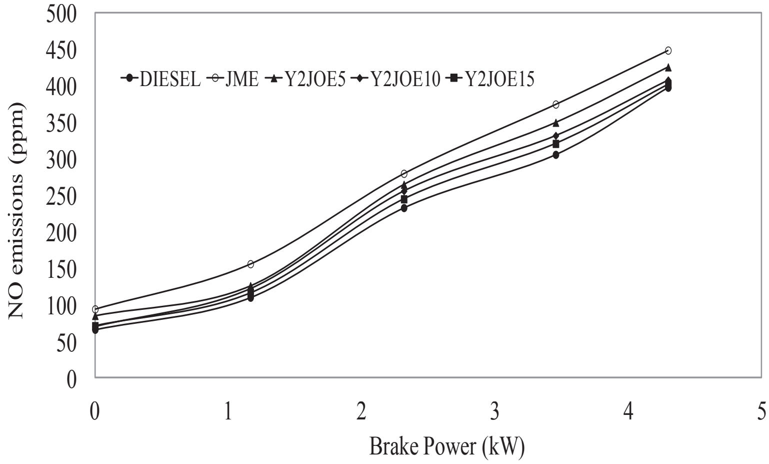


Fig. 5. Variation of NO emissions with brake power

It can be observed from the figure that the NO emissions of the JME operation are higher compared to JME-WPO emulsions as well as diesel operation. The presence of oxygen molecule in biodiesel causes an increase in combustion gas temperature resulting in a marginal increase in NO emissions [14]. Also it can be observed that the NO emission decreases with the addition of WPO content in the emulsions. This may be due to the water content present in the WPO which will reduce the combustion temperature [15].

3.2.3 Smoke density

In diesel engine smoke formation generally occurs in the fuel rich zone at high temperature, particularly within the core region of fuel spray. Fig. 6 depicts the variation of smoke density with brake power.

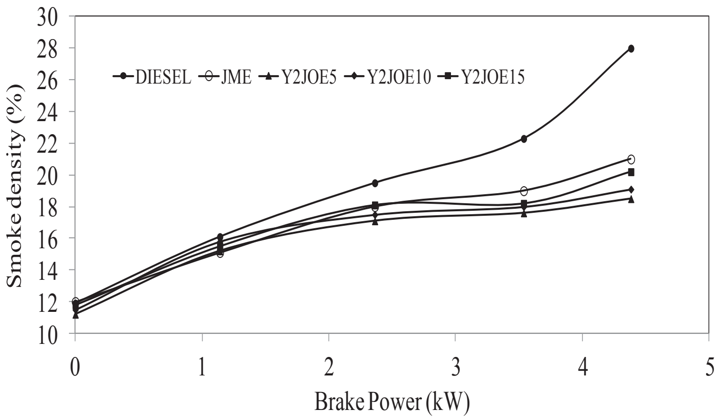


Fig. 6. Variation of smoke density with brake power

It can be viewed from the figure that the smoke density of JME, Y2JOE5, Y2JOE10 and Y2JOE15 are lower by 25, 33.9, 31.7 and 27.8% respectively than that of diesel fuel at full load. The significant reduction in smoke emission may be due to the presence of oxygen in JME and JME-WPO emulsions [16].

4. Conclusions

The performance and emission characteristics of a single cylinder, 4-stroke, direct injection diesel engine using three different JME-WPO emulsions were investigated and compared with the neat JME operation. It is observed from the figure that the brake thermal efficiency of the Y2JOE5 and Y2JOE10 emulsions are 2.8% and 5.3% higher than that of diesel fuel. For Y2JOE15 emulsions the thermal efficiency drops by 11.6%. The BSFC values of JME, Y2JOE10 and Y2JOE15 are higher than diesel fuel operation. JME and JME-WPO emulsions emit lower green house gas emissions to the environment. The NO emissions of JME-WPO emulsions exhibit declining trend with WPO addition. Smoke density of JME and JME-WPO emulsions are found to be lower than diesel fuel operation.

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